Sites Dam Site

The Sites Dam site is in a narrow, V-shaped water gap on Stone Corral Creek about a quarter of a mile east of the town of Sites and 8 miles west of the town of Maxwell in Colusa County (Photo 2). It is in Sec. 20, R4W, T17N on the Sites 7.5-minute USGS topographic quadrangle. The proposed dam, in conjunction with the Golden Gate Dam and the Sites northern saddle dams, would impound 1.8 million acre-feet of water in Sites Reservoir. The dam would be a 277-foot high embankment structure with a 900-foot crest length at an elevation of 540 feet. No spillway is associated with Sites Dam. The only spillway is part of the Golden Gate outlet works just south of the Golden Gate Dam site.

Previous geologic work was performed by USBR in the early 1960s with additional work in the early 1980s. This included geologic mapping at the site and drilling two vertical drill holes and one angle hole along the proposed axis. The current investigation by the Northern District and Project Geology staff consists of additional geologic mapping, diamond core drilling, and auger holes.

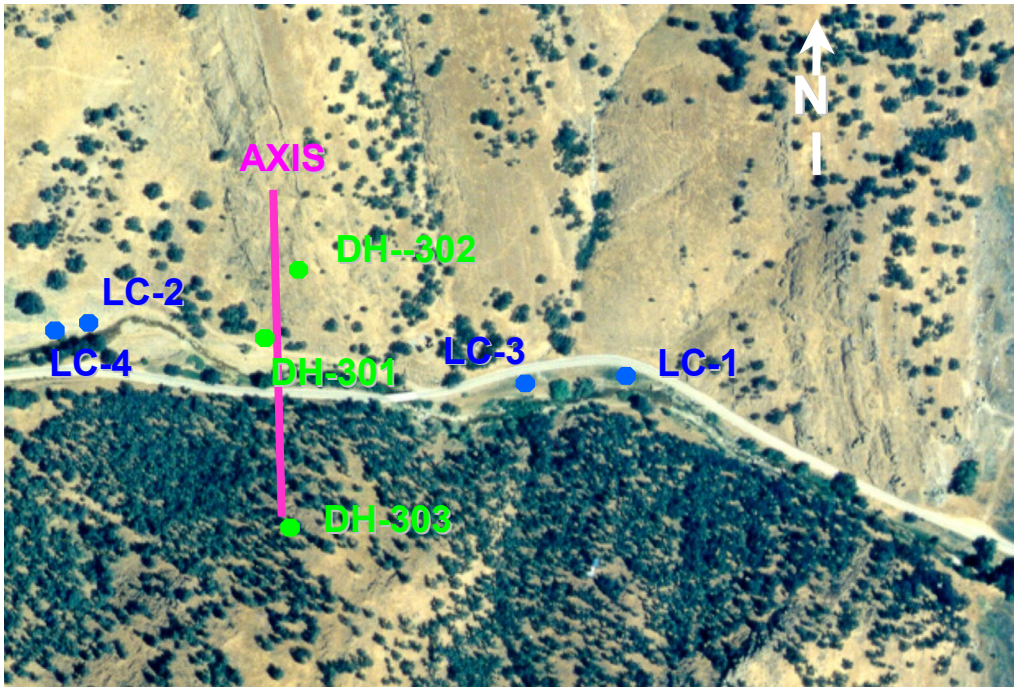


Photo 2: Aerial view of Sites Dam site on Stone Corral Creek

Dam Site Geology

The site was first mapped by USBR in 1963 as part of its *West Sacramento Canal Unit Report* (DOI-USBR 1964). This information was used as the basis for Northern District's geologic mapping of the site July through October of 1998. DWR's Division of Engineering assisted with this project, and mapping data from DWR's DOE and Northern District have been incorporated into this report.

Foundation rocks at the proposed Sites Dam site are Cretaceous sedimentary rocks of the Cortina and Boxer Formations that are upturned to form a series of north- to northwest-trending homoclinal ridges that dip from 45 to 55 degrees to the east. The sandstones and siltstones are more resistant and form ridge crests in the area. The proposed axis for the dam keys into one of these prominent ridges. The mudstones are generally covered by soil and colluvium and occupy topographic lows. The mudstones are rarely exposed in outcrops except in road cuts, streambanks, or where exposed from landslide scarps. Minor colluvial soil also mantles the abutments. Quaternary alluvial deposits cover bedrock in the stream channel to depths of about 5 feet. Quaternary terrace deposits also border the channel and have a thickness of about 20 feet. They are composed of sand, silt, and gravel, mantled by a clayey soil.

Plates 1 through 3 present the geologic mapping along with geologic cross sections and profiles, core logs, water pressure testing values, and minimum/maximum water levels at the site. Detailed logging and photodocumentation of the drill core is presented in Technical Memorandum A. Details of the water pressure testing are presented in Technical Memorandum B. Details of the piezometer construction and water levels are presented in Technical Memorandum C.

Bedrock Units

The proposed Sites Dam foundation consists of interlayered beds of Upper Cretaceous sandstone, siltstone, mudstone, and very minor conglomerate of the Boxer and Cortina Formations. Mudstone of the Boxer comprises about 50 percent of the foundation mainly upstream of the axis, with sandstone, siltstone, and minor conglomerate of the Cortina comprising the downstream 50 percent of the total footprint of the dam. This is detailed on Plate 2, Engineering Geology of the Sites Dam Site map.

These bedrock units were differentiated into mappable units (see Plates 1 through 3) as follows:

- KCVs - predominantly silty sandstone (70 to 100 percent) of the Venado member of the Cortina Formation with mudstone beds (0 to 30 percent) up to 5 feet in thickness.

- KCVsm - interbedded mudstones (30 to 70 percent) and silty sandstones (30 to 70 percent) of the Venado member of the Cortina Formation

- KBm - predominantly mudstone (70 to 100 percent) of the Boxer Formation with silty sandstone intervals (0 to 30 percent) up to 5 feet in thickness

The sandstone unit is the most resistant rock type at the site. Fresh sandstone is light to medium olive gray in color but yellowish brown when weathered. It is mostly very fine-to-medium grained, well-sorted, arkosic sandstone with a silt to clay matrix. Bedding is mostly massive to cross-bedded and ranges from less than a foot to tens of feet in thickness. It contains thin interbeds of siltstone and mudstone that range from laminar up to 5 feet in thickness. It is typically weathered at the surface to a depth of at least 15 feet. When fresh it shows no slaking. It is moderately to well indurated, moderately to slightly fractured, moderately hard to very hard, and moderately strong to strong. Internal structure is well developed in the areas of cross-bedding and vague where massive The fractures are commonly healed with calcite, and also have some pyritization.

The mudstone unit is the least resistant rock type in the area. It is low to moderately hard, weak to moderately strong, and is dark gray to black where fresh, and tan where weathered. Bedding is thinly laminar with thin sandstone and siltstone interbeds. It is brittle and slakes rapidly in outcrop when exposed to air and moisture. It is moderately indurated to friable, moderately hard to weak, and closely fractured.

A thin conglomerate unit outcrops just downstream of the left abutment. It is not exposed within the proposed footprint of the dam. Clasts range in size from coarse gravel to cobble. They are well-rounded and consist of chert, volcanic, and plutonic rocks. The clasts are hard and strong. The matrix is argillaceous. Some marine fossils are also associated with this unit. These have yet to be identified but appear to be pelecypod, coral, and gastropod fragments.

Unconsolidated Deposits

Unconsolidated deposits at the dam foundation consist of Quaternary stream channel deposits of sand and gravel, stream terraces, colluvium, and landslides.

Quaternary Alluvium (Qal) is the active stream channel of Stone Corral Creek and consists mainly of lean clay, silt, sand, gravel, cobbles, and boulders. It occurs along the channel sides and as discontinuous deposits in the channel. Deposits are estimated to range up to 5 feet in thickness.

Two terrace deposits (Qt1 and Qt2) border the active stream channel both upstream and downstream of the dam axis. They are flat and discontinuous and are

elevated 15 to 25 feet above the stream channel. They range from about 30 feet in width at the downstream toe of the footprint to over 300 feet just upstream of the footprint. Qt1 is the youngest. Soil development is moderate. The upper part of this terrace is clayey silt with increasing clay content downward. Occasional gravel lenses are exposed along the sides of the incised stream channel and encountered in several of the drill and auger holes. In places there is a clay bed at the base of the observable deposit. The color of the upper 3 feet is very dark grayish brown, grading lighter with depth. These terraces may be correlative with the Modesto Formation as mapped by Helley and Harwood (Calif., Sacramento Valley 1982).

Colluvium occurs at the base of the steeper slopes and consists of clayey silt and sand with angular cobble and boulder rock fragments. This deposit ranges from 2 to 5 feet in thickness.

Twelve areas of potential zones of instability, including landslides, have been mapped at or near the proposed dam axis. Eight of these occur within the dam footprint, with an additional four located just upstream of both abutments. Three of these may be associated with the S-2 fault that crosses the upstream end of the right abutment, then bisecting the channel and crossing the left abutment downstream of the dam footprint. Two shallow debris slides occur about 500 feet downstream of the dam axis on the right abutment and channel. Both would be removed during the stripping for the foundation excavation. The remainder of the landslides occur mostly within the mudstone unit of the Boxer Formation, just upstream of the dam axis on both abutments near the formational contact between the Boxer and Cortina as shown on Plate 2. Most of these are earth flows and debris slides; however, several rockfall talus deposits occur, especially along the base of the ridge-forming Venado sandstone. These upstream zones of instability and landslides comprise about 30 percent of the surficial area within the dam footprint.

Structure

The primary structural feature at the Sites Dam site is the northerly striking, easterly dipping homoclinal bedding of the Great Valley sequence. Local bedding attitudes mostly strike from N10°W to N10°E and mostly dip from 45 to 55 degrees east. These are consistent with the regional trend in the Great Valley sequence.

Faults and Folds

Fault S-2 was mapped by USGS (Calif., Glenn and Colusa Counties 1961) as a northeast-trending right lateral tear fault (Photo 3). It extends from near the town of Sites and trends about N70°E across the right abutment just above the dam crest, crossing the channel just downstream of the toe of the footprint, trending more northerly on a bearing of about N40°E (see Plate 2). This right lateral fault has an apparent offset of about 120 feet.

Although it is unrecognized by USBR mapping, the Salt Lake fault or associated deformation may intersect the proposed dam footprint, according to DWR. The Salt Lake fault was mapped by William Lettis and Associates (WLA 1997) along the eastern edge of Antelope Valley about a half mile upstream of the proposed dam axis. There is some indirect evidence suggestive of faulting upstream of the dam axis on the left abutment and in the channel. This includes high angle normal slickensides in outcrop, a broad area of slickensided float upslope of this outcrop, several landslides on the left abutment, and some shearing encountered in DWR and USBR channel drill holes. However, these features by themselves could not justify placement of a discrete fault trace.

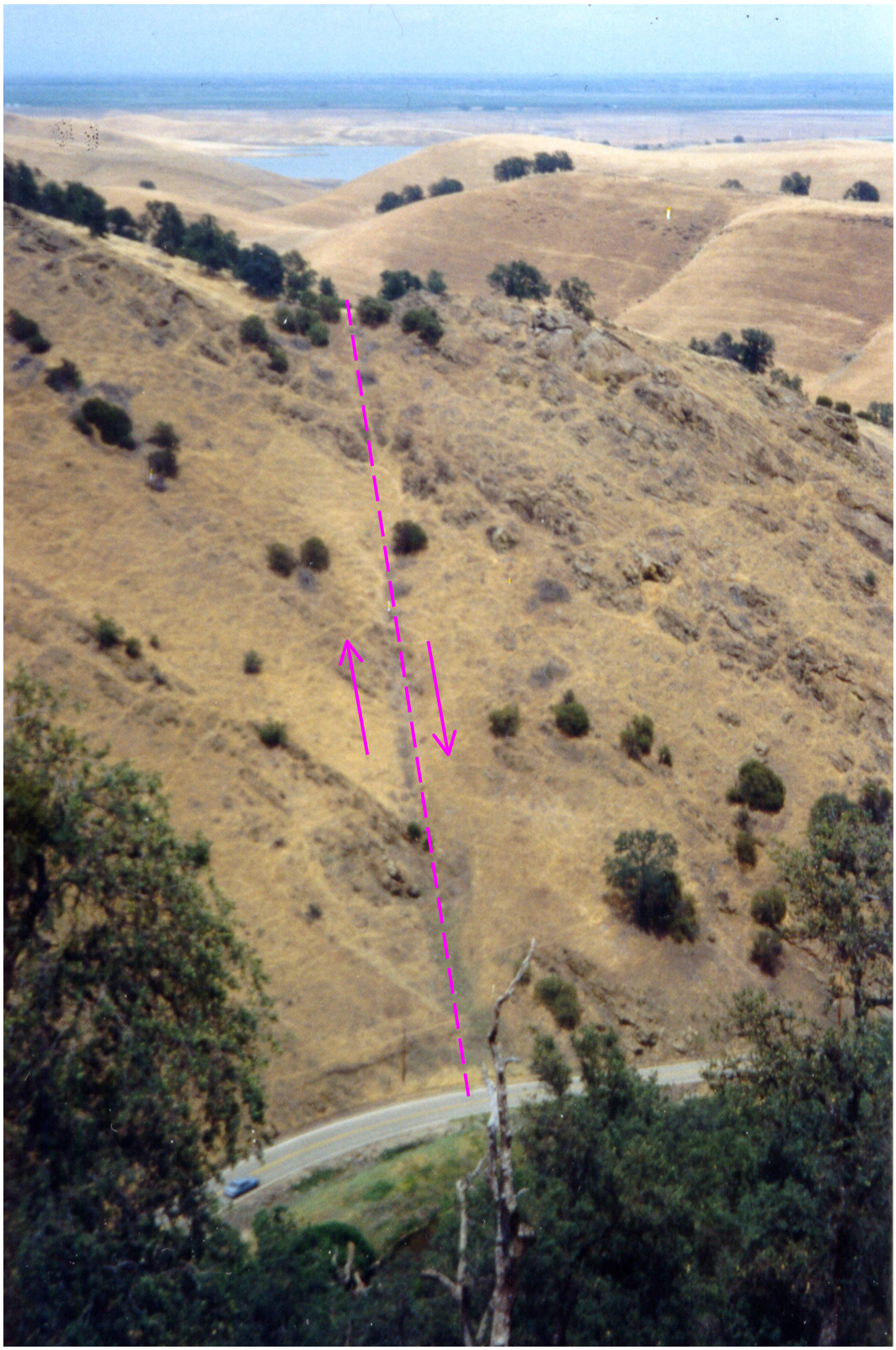


Photo 3. NE view of S-2 fault downstream of proposed Sites Dam footprint. (Note Funks Reservoir in the background)

Joints

At least two separate joint sets have been mapped in the area of the dam site. The primary and most distinctive jointing strikes NE and northwesterly dips ranging from 50 degrees to near vertical. This jointing is expressed on the left abutment, where intersections of these joints with the 175-foot-thick ridge-forming massive Venado sandstone has governed drainage off the ridge as steep gullies to the southwest. Secondary jointing exists at about N70°W with a wide range of dips. This is noted on the left abutment but becomes more apparent on the right abutment.

Foundation Conditions and Exploration

The rock at Sites Dam site should provide a good foundation for the proposed dam with moderate clearing and stripping. We have verified the existence of at least one fault in the right abutment, and our investigation suggests that another may exist in the channel and the left abutment. Also, both abutments contain zones of instability, including landslides that may require a moderate degree of excavation. Table 2 summarizes the foundation conditions.

The site was mapped on a regional scale initially by USGS in 1961, later by USBR in 1980, then modified by DWR-ND with assistance from DWR-DOE. In general, the lithology consists of upturned Upper Cretaceous sedimentary rocks consisting of dominant sandstone, mudstone, and minor conglomerate. The units strike roughly north-south, parallel to the axis, and dip downstream 45 to 55 degrees to the east. The foundation bedrock consists of about 50 percent sandstone and 50 percent mudstone interbeds (Figure 4). However, these percentages vary. The relative percentages of sandstone increases markedly in the main ridge, with a 160-foot thick sandstone layer in the Venado member of the Cortina Formation underlying the proposed dam axis. The Boxer Formation is immediately adjacent upstream. This has a predominant mudstone percentage of up to 70 percent, with secondary sandstone and siltstone interlayers to 30 percent, the reverse of the Cortina Formation. The channel between the abutments contains about 21 percent alluvium, 66 percent terrace deposits, and 13 percent landslide deposits.

In 1979-80 USBR drilled and water pressure-tested three diamond core holes along the proposed axis on both abutments and in the channel. Accordingly, our drilling concentrated on evaluating existing faults in the foundation. In the spring of 1998 we contracted with All -Terrain Drilling to provide drilling and testing services. An all-terrain CME-850 track mounted rig mobilized and started work at the site. Four diamond core holes were drilled totaling 740.4 feet; and three auger holes totaling 41.4 feet (Table 3). All four of the core holes were angle holes oriented to intercept the northeast-trending tear fault, and/or to explore the possibility of an extension of the Salt Lake fault or associated deformation intercepting the proposed dam footprint.

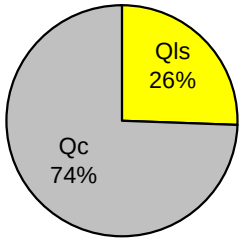
TABLE 2 – Sites Reservoir Project, Sites Dam Site Foundation Conditions (total area of Dam site footprint = 1,117,800 feet^2)

FEATURE	SURFICIAL/BEDROCK GEOLOGY (by area in feet^2)*	CLEARING ESTIMATES	STRIPPING ESTIMATES	WATER LEVELS	GROUTING ESTIMATES	STRUCTURAL REMARKVS
Left Abutment Axis Length = 365 feet. Max Footprint Length = 1,571 feet Min Elev. = 255 feet Max Elev. = 540 feet USBR Drill holes = 60 degree angle drill hole DH-302 (placed 280 feet. north of channel 180 feet. up the left abutment just downstream of the dam axis) No DWR Drill holes. No seismic done.	Surficial Qls = 100,100 feet^2 (26%) Qc = 291,700 feet^2 (74%) Total Area = 391,800 feet^2 Bedrock KCVs = 107,700 feet^2 (28 %) KCVsm = 130,600 feet^2 (33%) KBm = 153,500 feet^2 (39 %) Total Area = 391,800 feet^2 Therefore: Ss = from 114,600 feet^2 (29%) to 306,600 feet^2 (78%) Ms = from 85,200 feet^2 (22%) to 277,200 feet^2 (71%)	Light: Scattered grasses interspersed between open sandstone outcrops. A few oaks in south draining gully.	The upper foot of soil, colluvium, landslide deposits, and intensely weathered rock can be stripped with common methods. An additional 14 feet of moderately weathered rock may need to be excavated.	USBR drill hole not measured.	USBR Drill Hole DH-302 Shows that this hole is in predominately impervious sandstone except where it is semi-pervious in the range of 28 to 38 feet in moderately weathered ss and in the 47 to 56 feet. where there are some thin beds of mudstone.	The north-south trending Salt Lake thrust fault (S-1) is mapped about 1/2-mile northwest of the damsite. It or associated deformation may intercept upstream end of dam footprint. Several earth and debris flows, rockfall off Ss ridge, exist upstream of dam axis. Total area of Qls = 102,100 feet^2, or about 26% of the abutment. USBR drill hole DH-302 shows little or no fracturing except between 3 to 15 feet where there is some moderate fracturing.
Channel Section Axis Length = 146 feet Max Footprint Length = 1,614 feet. Min Elev. = 250 feet Max Elev. =295 feet USBR Drill holes =DH-301 (Placed left of channel along dam axis). DWR Drill holes LC-2, LC-4, AUG-1, and AUG-2 are located 350, 450, 405, and 975 feet, respectively upstream of the dam axis. DWR Drill holes LC-1, LC-3, and AUG-3 are located 820, 770 and 710 feet respectively down steam of the dam axis. AUG-2 is the only hole located outside of footprint. No seismic done.	Surficial Qls = 38,700 feet^2 (13%) Qal = 63,700 feet^2 (21%) Qt_1 = 205,000 feet^2 (66%) Total Area = 307,400 feet^2 Bedrock KCVs = 29,100 feet^2 (9 %) KCVsm = 42,200 feet^2 (14 %) KBm = 236,100 feet^2 (77 %) Total Area = 307,400 feet^2 Therefore: Ss = from 33,000 feet^2 (11%) to 223,900 feet^2 (73%) Ms = from 83,500 feet^2 (27%) to 274,400 feet^2 (89%)	Light: Light riparian bordering stream = grasses, cotton-wood, fig trees, poison oak; grasses on terrace deposits	The upper 4 to 20 feet of alluvium terrace deposits, and intensely weathered rock can be stripped with common methods. An additional 3 feet of moderately weathered rock may need to be excavated.	In Dec. 1979 DH-301 varied from 10-10.2 feet below surface. In Summer, 1998, DWR holes = 9.5 feet below surface, then constant till Summer, 1999 = 11.5 feet below surface. Changed in Nov. 1999 to 10 feet. below surface.	DWR Drill Hole LC-3: Moderate grout takes at 79 to 88 feet in fractured Ss/Ms. Low grout takes at 71 to 79, and 88 to 95 feet in fractured Ss/Ms. Rest of hole little grouting. DWR Drill Hole LC-4 (upstream of dam axis): High grout takes at 18 to 35 feet, 69 to 93 feet in fractured Ms/Ss. Moderate grout takes at 35 to 44 feet in fractured Ss/Ms. Low grout takes at 44 to 58 feet 62 to 69 feet, 93 to 100 feet, and 117 to 126 feet. in fractured Ms/Ss. The rest requires little grouting.	Mapped Fault (S-2) trends through channel just at downstream toe of footprint, then continues at N42^{o}E, dips >80^0 SE. Apparent right lateral offset = 120 feet. USBR drill hole DH-301 intercepts zones of very intense Fx from 19 to 20 feet and with shears containing slicks and gouge at 78 to 80 feet, 88.6 to 89.4 feet and 104 to 107 feet DWR drill hole LC-1 did not intercept any shears. Drill hole LC-2 intersects slicks and gouge 40 feet and from 194 to 195 feet, with intense Fx from 112 to 121 feet. Drill hole LC-3 intercepted closely to intense Fx and slicks from 24 to 29 feet and from 76 to 80 feet. Drill hole LC-4 intercepted closely to intense Fx and slicks at 60 to 61 feet., 101 feet.,104 feet., 136 to 138 feet, 177 feet., and 194 to 195 feet Note: Angle depths for the DWR holes.
Right Abutment Axis Length = 415 feet. Max Footprint Length = 1,601 feet. Min Elev. = 250 feet. Max Elev. = 540 feet. USBR Drill holes = DH-303 (placed 520 feet. south of channel 240 feet. up the right abutment along the dam axis) No DWR Drill holes. No seismic done.	Surficial Qls = 180,400 feet^2 (43%) Qc = 238,200 feet^2 (57%) Total Area = 418,600 feet^2 Bedrock KCVs = 109,837 feet^2 (27%) KCVsm = 89,600 feet^2 (21%) KBm = 219,200 feet^2 (52%) Total Area = 418,600 feet^2 Therefore: Ss = from 103,800 feet^2 (25%) to 326,000 feet^2 (78%) Ms = from 92,700 feet^2 (22%) to 314,900 feet^2 (75%)	Moderate: Heavier than left abutment due to abundant oak trees and poison oak, especially upstream of axis on old landslide deposit.	The upper 9 feet of soil, colluvium, landslide deposits, and intensely weathered rock can be stripped with common methods. An additional 40 feet of moderately weathered rock may need to be excavated.	DH-303 varied during drilling Feb. 1980, from dry to 125 feet below ground surface to dry again. This USBR drill hole has not measured since.	USBR Drill Hole DH-303 Shows that this hole is predominately impervious sandstone some thin and laminated beds of mudstone except where it is semi-pervious in the range of 31 to 86 feet it is lightly moderately weathered and in the 132 to 141 feet range where it corresponds to some very intense fracturing.	Mapped Fault (S-2) trends at N72^{o}E along southern edge of footprint, dips >80^0 SE. Apparent right lateral offset = 120 feet. USBR drill hole DH-303 shows little to intense fracturing with a zone of very intense fracturing 108.9-109.6 feet and 155.7-155.9 feet Note: these are angle depths.

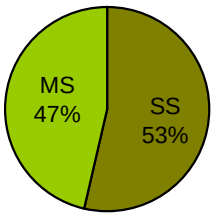
Ss = Sandstone Ms = Mudstone Cgl = Conglomerate Qal = Quaternary Alluvium Qc = Quaternary Colluvium Qt_1 = Quaternary Terrace (lower) Qt_2 = Quaternary Terrace (upper) Fx = fracturing
***Total Foundation Area of Damsite Footprint = 1,117,800 feet^2, therefore total Ss = from 251,400 feet^2 (22%)to 856,500 feet^2 (77%); total Ms = from 261,400 feet^2 (23%) to 856,500 feet^2(78%)**

FIGURE 4: Sites Dam Site Surficial and Bedrock Lithology By Percentage

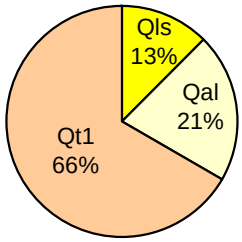
Areal Surficial Lithology of the Left Abutment



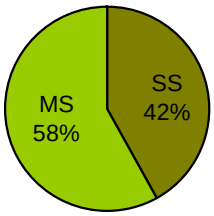
Areal Bedrock Lithology of the Left Abutment -Average Proportion of Sandstone and Mudstone



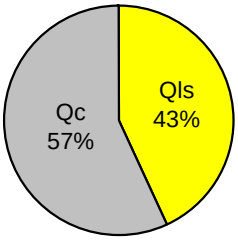
Areal Surficial Lithology of the Channel Section



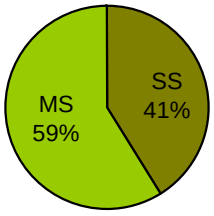
Areal Bedrock Lithology of the Channel Section--Average Proportion of Sandstone and Mudstone



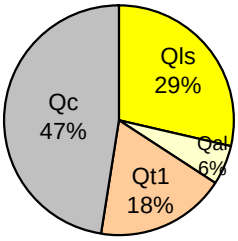
Areal Surficial Lithology of the Right Abutment



Areal Bedrock Lithology of the Right Abutment--Average Proportion of Sandstone and Mudstone



Areal Surficial Lithology of the Damsite Footprint



Areal Bedrock Lithology of the Damsite Footprint--Average Proportion of Sandstone and Mudstone

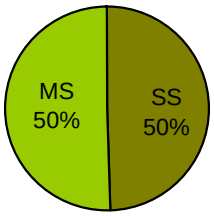


Table 3. DWR drilling footage of Sites Dam site

Drill site	Drill hole	Date started	Date completed	Drilled footage (feet)
Sites Dam site	LC–2	May 11, 1998	May 20, 1998	202.2
	LC-1	MAY 22, 1998	May 28, 1998	140.6
	LC-3	June 01, 1998	June 05, 1998	198.0
	LC-4	JUN 10, 1998	JUN 16, 1998	199.6
Total HQ Diamond Drill Footage				740.4
	AUG-1	MAY 21, 1998	MAY 21, 1998	10.5
	AUG-2	MAY 22, 1998	MAY 22, 1998	16.9
	AUG-3	MAY 22, 1998	MAY 22, 1998	14.0
Total Auger Footage				41.4
Total footage				781.8

LA = Left abutment drill hole
LC = Left channel drill hole
RC = Right channel drill hole
RA = Right abutment drill hole
DHPP = Drill hole power plant
DHS = Drill hole spillway
DHT = Drill hole tunnel
SSD = Sites saddle dams
AUG = Auger hole

Water pressure testing was also performed on two of these holes, LC-2 and LC-4, to determine the permeability of the Boxer Formation upstream of the dam axis and the presence of any faults, associated shearing, and/or fracturing (see Plates 2, 3, and Technical Memorandum C). Three holes were augered through the terrace and alluvial deposits to bedrock.

Angle drill hole LC-2 was drilled to evaluate the possible existence of the Salt Lake fault or associated deformation in the upstream footprint of the proposed dam axis (Photo 4). It was oriented cross-channel at S62°W to also explore the possibility of a "blind" or hidden fault under the alluvium that trends nearly parallel with Stone Corral Creek. It was drilled to a total depth of 202.2 feet. The upper 0.0 to 20.5 feet are composed of terrace deposits consisting of a mostly lean clay. From 20.5 to 39.0 feet, the hole drilled through 80 percent mudstone with 20 percent siltstone interbeds. From 39.0 to 50.7 feet, the hole drilled through 50 percent mudstone and 50 percent siltstone interbeds. From 50.7 to 72.0 feet, it intersected 80 percent sandstone with 20 percent mudstone interbeds. From 72.0 to 202.2 feet, the hole drilled through 80 percent mudstone with 20 percent sandy siltstone interbeds. It also intersected minor shears from 39.7 to 39.9 feet, 194.2 to 194.7 feet, and a shear zone from 111.7 to 121.0 feet. These zones contained slickensides and fracturing that may be related to the S-2 fault (Photo 5).

Photo 4. CME - 850 drill rig at Sites Dam site drill hole LC–2

Angle drill hole LC-4 was drilled roughly 100 feet southwest of LC-2 at S86°W to further evaluate the Boxer Formation underlying the upstream portion of the dam footprint, and to explore the possibility that more shears may parallel the ones found in LC-2. The upper 0.0 to 18.3 feet of the hole drilled through a terrace deposit consisting of a sandy clay. From 18.3 to 44.6 feet, it drilled through 70 percent mudstone with 30 percent siltstone interbeds. From 44.6 to 60.1 feet, it intersected 50 percent mudstone and 50 percent siltstone interbeds. From 60.1 to 76.5 feet, the hole contains 90 percent mudstone with 10 percent siltstone interbeds. From 76.5 to 169.6 feet, the hole contains 60 percent mudstone with 40 percent siltstone interbeds. From 169.6 to 174.3 feet, it hit a 100 percent sandstone layer.

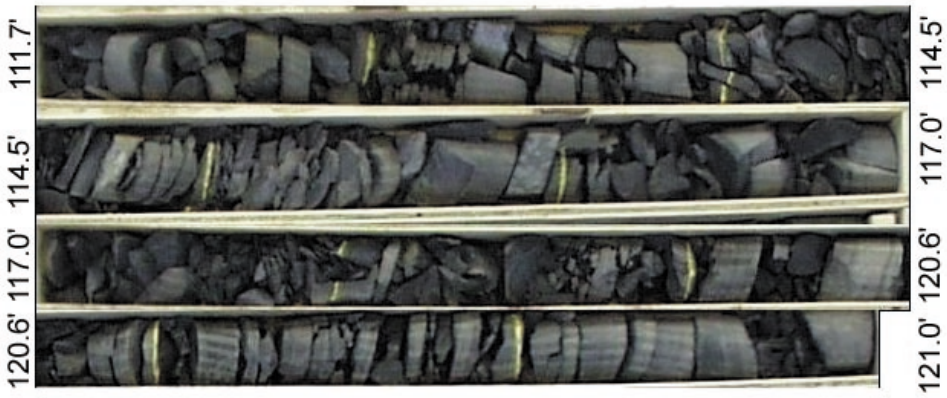


Photo 5. Intense fracturing from 111.7 to 121.0 feet in drill hole LC-2

From 174.3 to 199.6 feet, the hole is composed of 60 percent mudstone with 40 percent siltstone interbeds. It also intersected slickensides and intense fracturing from 60.3 to 61.1 feet, 101.1 to 101.6 feet, at 104.0 feet, and from 136.2 to 136.6 feet, 137.4 to 137.7 feet, 176.7 to 177.1 feet, and 194.0 to 194.9 feet. The hole did not encounter any significant shearing, although minor slickensides were encountered throughout the hole.

Angle hole LC-1 was drilled to intercept the S-2 fault as mapped and to explore the possibility that a buried or hidden fault trends beneath Stone Corral Creek. It drilled through lean clay terrace deposits to 21.0 feet. The rest of the hole to 140.6 feet intercepted about 95 percent sandstone with 5 percent thin mudstone interlayers. No fault was encountered, so the drill rig was moved to drill hole LC-3.

Angle hole LC-3 was oriented nearly perpendicular to the mapped trend of S-2 fault. It drilled through sandy clay terrace deposits to a depth of 7.1 feet. No core was recovered from 7.1 to 18.9 feet. From 18.9 to 198.0 feet, the hole encountered 95 percent sandstone with 5 percent thin mudstone interlayers. It also encountered a zone of close fracturing of rock and slickensides from 24.0 to 28.5 feet and a zone of fractured rock and slickensides from 76.3 to 80.0 feet. These are probably related to the S-2 fault but are probably not the main zone of shearing.

USBR drilled vertical drill hole DH-301 in 1979 at the proposed dam axis about 380 feet downstream of LC-2. It encountered very intense fracturing from 19.1 to 20.0 feet and slickensides and gouge from 78.3 to 80.0 feet, 88.6 to 89.4 feet, and 103.9 to 106.7 feet. Although not correlative with the shearing in LC-2 and LC-4, these features may also represent deformation associated with the Salt Lake fault, or the contact between the Boxer and Cortina Formations.

Auger holes AUG-1, AUG-2, and AUG-3 were drilled to determine the composition and thickness of the terrace deposits in the channel. Bag samples were taken every 5 feet. The terraces are composed mostly of clayey silts with minor gravels and range in thickness from 10.5 to 16.9 feet.

On June 10 the drill rig was moved north to explore the Golden Gate Dam site.

Rock Strength

Logging of the core indicates that the rock strength of the sandstone ranges from moderate to hard. Rock quality designation (RQD) was used by both USBR and DWR in logging of the core (see Table 4 and Plate 3). This

Table 4. Rock quality designation in drill holes at Sites Dam site

Agency	Drill Hole	Vertical Depth Interval (feet)	Minimum RQD*	Maximum RQD*	Average RQD*	Description
DWR	LC-1	25 – 100	84	100	96	Excellent
DWR	LC-2	25 – 37	16	78	41	Poor
DWR	LC-2	38 – 51	77	100	89	Good
DWR	LC-2	52 – 86	22	86	55	Fair
DWR	LC-2	87 – 143	68	94	85	Good
DWR	LC-3	25 – 55	95	100	98	Excellent
DWR	LC-3	56 – 57	0	0	0	Very Poor
DWR	LC-3	58 – 94	76	100	92	Excellent
DWR	LC-3	95 – 112	58	100	82	Good
DWR	LC-3	113 – 140	86	100	93	Excellent
DWR	LC-4	25 – 74	0	72	32	Poor
DWR	LC-4	75 – 117	38	100	76	Good
DWR	LC-4	118 – 142	20	88	59	Fair
USBR	DH-301	10 – 23	0	35	9	Very Poor
USBR	DH-301	24 – 59	64	100	82	Good
USBR	DH-301	60 – 61	9	9	9	Very Poor
USBR	DH-301	62 – 108	20	100	77	Good
USBR	DH-302	25 – 130	88	100	99	Excellent
USBR	DH-303	10 – 28	0	30	12	Very Poor
USBR	DH-303	29 – 63	33	87	54	Fair
USBR	DH-303	64 – 76	80	100	87	Good
USBR	DH-303	77 – 90	35	47	39	Poor
USBR	DH-303	91 – 128	62	100	85	Good
USBR	DH-303	129 – 133	28	28	28	Poor
USBR	DH-303	134 – 180	81	100	98	Excellent
USBR	DH-303	181 – 193	41	80	61	Fair
USBR	DH-303	194 – 206	86	100	95	Excellent

parameter is often used as an indicator of the competence of rock. In general, calculation of RQD indicates that the left abutment along the Sites Dam site axis has excellent rock quality deeper than 25 feet. Also, quality in the channel upstream of the axis in the Boxer Formation is fair to good below 75 feet. Quality in the channel along the axis is good below 62 feet. Quality in the channel downstream of the axis in the Venado sandstone is good to excellent below 58 feet. Quality on the right abutment along the axis is fair to excellent below about 90 feet in depth.

Bryte Laboratory tested several fresh samples of sandstone core from drill hole LC-2. A sample from 53.5 to 54.5 feet was tested wet and had a specific gravity of 2.55, a 1.6 percent loss, and unconfined compressive strength (UCS) of 17,868 pounds per square inch (psi). Sandstone samples were also taken from Sites Quarry about 2,000 feet downstream of the dam site and tested. Three fresh sandstone samples had a UCS of 9,568 psi when dry, 6,983 psi when wet. Three moderately weathered sandstone samples averaged a UCS of 4,998 psi when dry, 3,589 psi when wet.

Water Pressure Testing

Water pressure tests were performed by DWR in angle drill holes LC-3 and LC-4. These holes generally had minimal water losses, but there were several intervals in which high losses were recorded. High losses occurred in drill hole LC-4 in the zones from 50 to 65 feet, and from 75 to 90 feet. Water losses were relatively low below these depths. About one psi per foot of overburden was used for water testing.

Grouting and Foundation Treatment

Grouting requirements focus on LC-4 to the west, where secondary fracturing of the predominately mudstone formation is associated with high Lugeon values. Average permeability for the mudstone in this hole is 0.26 feet per day, with grouting necessary throughout the top 140 feet of the hole. The remainder of the hole will require moderate to no grouting. The eastern-most drill hole, LC-3, is composed mainly of sandstone, with an average permeability of 0.04 feet per day. Grouting in this hole will center on the fractured zone encountered between 100 feet and 135 feet, with the balance of the hole requiring moderate to low grouting. This hole has an average Lugeon value of 1, which is significantly lower than the mudstone of LC-4 (average Lugeon value of 6). LC-1 and LC-2 were not water pressure tested due to problems with the packers.

Faults uncovered in the foundation may require some cleaning and excavation of weakened and sheared rock before the embankment is constructed. These faults/shears, bedding, and jointing are potential seepage paths through the abutments and will undoubtedly require grouting. Therefore, for estimating

purposes, blanket grouting should be considered to seal near-surface fractures and joints.

Water Levels

Piezometers were installed in drill holes LC-2, LC-3, and LC-4 at the Sites Dam site. Water levels have been monitored since the summer of 1998. The water level in the channel holes was roughly 9.5 feet deep just after drilling in the summer of 1998, then remained fairly constant until the summer of 1999 when it dropped to about 11.5 feet deep. It then rose to about 10 feet deep by the winter. The water level on the right abutment was 125 feet deep when measured in DH-303 by USBR in February 1980.

Clearing and Stripping

Photo 6. Sites Dam site left abutment

Left Abutment

The left abutment is moderately steep adjacent to the channel section. It has a slope ranging from 1:1 at the base, then lessening to 0.75:1 towards the crest. (Photo 6). The sandstone forms the topographic highs often void of soil cover. Mudstone is mostly subdued in topographic expression and develops a colluvial soil overburden. These beds strike nearly north-south and dip about 50 degrees

downstream toward the east. Most joint fractures strike nearly east-west with a dip between 70 degrees south to 70 degrees north. Vegetation is light on the left abutment, consisting mostly of grass with a few scattered oaks, especially in the south-draining gullies upstream of the axis.

The unconsolidated deposits on the left abutment consist of about 74 percent colluvial soil and 26 percent landslide deposits. This is underlain on average by about 55 percent sandstone and siltstone, with 45 percent mudstone interlayers.

Foundation preparation should include the removal of at least the upper foot of colluvial soil, landslide material, and heavily weathered bedrock using common methods, with another 14 feet of moderately weathered bedrock that may have to be excavated. The material removed from the foundation stripping probably can be used as random fill. The upper 1-foot of soil, colluvium, and intensely weathered bedrock on the left abutment can be stripped using common methods.

Channel

Photo 7. Downstream view of the channel at Sites Dam site

The channel varies in width from about 75 to 450 feet in the footprint, and averages about 150 feet at the dam axis (Photo 7).

Alluvial cover is superficial with about 4 to 10 feet of poorly to well-graded sand and gravel. No bedrock was observed in the channel of Stone Corral Creek within the footprint of the dam. The creek has perennial flows, so a creek diversion or impoundment will be necessary. The flow in the summer and fall is generally minimal, and dewatering will not be a serious problem.

The channel has a fairly light riparian zone with scattered pockets of grasses, cottonwoods, fig trees, and poison oak. This is thicker in the channel along the dam axis where the channel narrows.

Stream channel deposits consisting of an areal proportion of 21 percent alluvium, 66 percent terrace deposits, and 13 percent landslide deposits overlie the channel. The underlying bedrock is estimated at about 42 percent sandstone and 58 percent mudstone.

Foundation preparation should include the removal of 4 to 20 feet of alluvium, terrace deposits, and intensely weathered bedrock using common methods, with at least another 9 feet of moderately weathered bedrock that may have to be excavated. In addition, the oversteepened slopes adjacent to and cut by the creek will require shaping.

Right Abutment

The right abutment is moderately steep with a natural slope of about 0.75 to 1 (Photo 8). The mudstone units mostly upstream of the dam axis are mostly covered by soil creep and/or colluvium and are generally only seen exposed in creek beds, roadcuts, and drill core. The sandstone can generally be observed as outcrops exposed as topographic highs with little or no soil cover. Minimal amount of colluvium and slope wash covers the mid to lower right abutment

Vegetation is much heavier on the right abutment than that on the left abutment. Oak trees cover much of the footprint and are especially dense just upstream of the dam axis on the Boxer Formation. This is associated soil development on the mudstones and a northern slope exposure along with an old extensive landslide deposit.

There are thicker soil and colluvial deposits on the Boxer Formation than on the Cortina because the Boxer contains a greater relative percentage of more erodible mudstone. The unconsolidated deposits on the right abutment consist of about 57 percent colluvial soil and 43 percent landslide deposits. This is underlain on average by about 40 percent sandstone and siltstone, with 60 percent mudstone interlayers.

Foundation preparation should include the removal of at least 9 feet of topsoil, colluvium, heavily weathered bedrock, and landslide and rock debris. In some locations intensely weathered bedrock can be excavated using common methods, with at least another 40 feet of moderately weathered bedrock that may have to be excavated. A reconnaissance-level investigation of Sites Dam site states, "Depth to groutable rock on the left abutment will average three feet. Deep slopewash accumulations on the right abutment will neccessitate 10- to 15-foot excavations to reach groutable rocks. Depths to groutable rock in the channel section will vary from five to eighteen feet. Temporary slopes of 1:1 on the

abutments and 1.5:1 in the channel section are recommended." (DOI-USBR 1969) The material removed by foundation stripping can probably be salvaged for use as random fill

Photo 8. Sites Dam site right abutment

Conclusions and Recommendations

DWR's Northern District Geology Section concludes that the foundation drilled appears to be suitable for the proposed structures. Table 2 summarizes the foundation conditions in the footprint for the proposed dam site. More conclusions follow:

- Mapped S-2 fault on Plate 2 is a near vertical linear feature that trends about N70°E on the upper right abutment along the southern edge of the footprint. It turns more northerly near the channel, trending N45°E downstream of the dam axis. This feature has an apparent right lateral offset of about 160 feet. USBR located angle drill hole DH-303 about 100 feet upslope of this fault and did not intercept it. DWR angle drill hole LC-3 drilled through slickensides and intense fracturing from 24.0 to 28.5 feet,and from 76.3 to 80.0 feet. These are probably related to the S-2 fault, but are probably not the main zone of shearing. The consulting firm of William Lettis and Associates concluded that there is no evidence of Quaternary fault movement along the S-2 fault where trenched to the northeast of the dam site. It is likely that this is also true in the footprint of the Sites Dam site.

- The Salt Lake fault was mapped by William Lettis and Associates (WLA 1997) along the eastern edge of Antelope Valley about a half mile

upstream of the proposed dam axis. The fault or associated deformation may extend into the proposed dam footprint. This is indirectly supported by high angle normal slickensides in outcrop on the left abutment, a broad area of slickensided float upslope of this outcrop, several landslides on the left abutment, and some shearing encountered in DWR and USBR channel drill holes. However these features by themselves could not justify placement of a discrete fault trace. DWR 45-degree angle DH LC-2 and LC-4 were drilled to determine whether this fault exists in the footprint. DH LC-2 was oriented at S62oW. It intersected slickensides and gouge from 39.7 to 39.9 feet and 194.2 to 194.7 feet and a zone of intense fracturing from 111.7 to 121.0 feet. LC-4 was drilled roughly 100 feet southwest of LC-2 at S86oW to continue this exploration. It intersected slickensides and intense fracturing from 60.3 to 61.1 feet, 101.1 to 101.6 feet, at 104.0 feet, and from 136.2 to 136.6 feet, 137.4 to 137.7 feet, 176.7 to 177.1 feet, and 194.0 to 194.9 feet. Also USBR's vertical DH-301 was placed in the left channel about 380 feet away at the proposed dam axis. It encountered very intense fracturing from 19.1 to 20.0 feet; and slickensides and gouge from 78.3 to 80.0 feet, 88.6 to 89.4 feet, and 103.9 to 106.7 feet. In the author's opinion these features may indicate deformation associated with the Salt Lake fault or may be related to the contact between the Boxer and Cortina Formations.

- In addition to the mapped fault traces, drill core data indicate that other minor faults and shears exist. The mapped fault traces and the minor faults and shears should not pose any unusual construction difficulties.

- The rock strengths should be adequate for the dam foundations as proposed.

- In general, the mudstone has the highest average permeability at 0.26 feet per day, followed by sandstone at 0.04 feet per day. Overall, the rocks have little primary permeability. Instead, zones of high water take are associated with the development of secondary permeability through weathering, extensive fractures, or jointing. This is most common in the sandstone.

- Grout takes were calculated for the proposed dam foundation in the channel from a Lugeon analysis of the water pressure testing (Technical Memorandum B). Estimates for the abutments were based on USBR's permeability values obtained during its drilling program. The grout takes on the left abutment in DH-302 are expected to be low except for moderate grout takes from 28 to 38 feet and 47 to 56 feet, and moderate grout takes from 50 to 62 feet in angle drill hole DH-303 on the right abutment. Additional exploration is warranted prior to construction to better evaluate where the S-2 fault intersects the right abutment. The takes in the channel downstream of the axis are also expected to be low except for moderate grout takes from 31 to 86 feet in moderately

weathered sandstone and mudstone, and from 132 to 141 feet in fractured sandstone and mudstone. A grout curtain to 100 feet under the foundation with 10- to 20-foot centers should be sufficient to control foundation seepage.

- Water levels were measured in the channel over the past two years with a minimum depth of 10 feet and a maximum depth of 12 feet. Depth to water on the right abutment is at least 125 feet. Depth on the left abutment is undetermined.

- There should not be a significant problem with clearing vegetation from the foundation. The heaviest vegetation growth is on the right abutment where oak trees are fairly dense, especially upstream of the dam axis. There are only scattered oaks on the left abutment and light riparian growth in the channel.

- Additional foundation preparation would include the removal of about 10 feet of colluvium, soil, and intensely weathered bedrock from the left abutment; 15 feet from the channel; and 10 feet from the right abutment. An additional 10 feet of fractured and moderately weathered rock may have to be excavated from the left abutment, 3 to 10 feet from the channel, and 10 feet from the right abutment.

Additional work prior to final design and construction should include:

- Performing seismic refraction surveys on the terrace deposits to determine rippability estimates of the foundation bedrock.

- Further evaluating the extent and depth of the landslide deposits upstream of the axis on the left and right abutments.

- Having DWR's Bryte Laboratory test representative mudstone and sandstone samples from the core for both dry and wet unconfined compressive strength.

- Specific grouting requirements will require additional drilling.